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THE OIL HEATING ASSOCIATION OF CANADA CLEAN AIR PROGRAM PHASE IV: EVALUATION OF BURNERS WITH HIGH AND LOW SPEED MOTORS IN A DOMESTIC HOT-WATER BOILER

by

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THE OIL HEATING ASSOCIATION OF CANADA CLEAN-AIR PROGRAM

PHASE IV: EVALUATION OF BURNERS WITH HIGH AND LOW SPEED MOTORS IN A DOMESTIC HOT WATER BOILER*

by

T. D. Brown**

ABSTRACT

Operation of six yellow flame burners at different firing rates (0.5, 0.75 and 1.00 US gph) in a domestic hot water boiler equipped with a refractory combustion chamber showed that several of the burner firing rate combinations tested (10 out of 18) could not meet a combined standard of excess-air below sixty per cent and a smoke number below one. Only one burner could meet the standard at all firing rates. The burners were generally least efficient and most susceptible to draft at the lowest firing rate.

The incorporation of a slip clutch resulted in a lower smoke index and peak carbon monoxide concentration during start-up and shut-down in 80% of the combinations tested.

The performance data confirms the conclusions from previous phases of the program that all burners are least satisfactory at the minimum firing rate.

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* Prepared for the Equipment and Service Committee of the Oil Heating Association of Canada, Chairman, C.S. James.

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LE PROGRAMME DE L'AIR PROPRE DE L'ASSOCIATION CANADIENNE DE CHAUFFAGE D'HUILE

PHASE IV: L'EVALUATION DES BRULEURS AVEC LES MOTEURS DE BAS ET HAUTE VITESSE DANS UNE CHAUDIERE DE L'EAU CHAUDE*

par

T. D. Brown**

RESUME

L'opération de six brûleurs à flamme jaune aux taux différents de combustible dans une chaudière domestique à l'eau chaude equippée d'une chambre de combustion tapissée de refractaire a montré que plusieurs combinaisons de brûleurs sur taux de combustible (10 sur 18) ne pouvaient pas rencontrer à la fois un niveau de combustion qui requiert un numero de fumée <1 et un niveau d'excèss d'air inférieur de soixante pour cent. Un seul brûleur pouvait rencontrer ces normes à chaque taux de combustible. Les brûleurs étaient les moins efficaces et les plus susceptibles au tirage de la cheminée quand ils etaient utilisées au taux de combustibles le plus bas.

Ces essais ont confirmé le conclusion antérieur que les brûleurs etaient les moins efficaces quand its étaient utilisées au taux de combustibles le plus bas.

Pendant les mises en marche et les arrêts des brûleurs l'incorporation d'un embrayage coulant entraina une diminution de fumée et une concentration de monoxide de carbon à quatre-vingt pour cent des combinaisons analysées.

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*Préparé pour le comité de l'equipement et service de l'association canadienne de chauffage d'huile directeur général C.S. James.

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INTRODUCTION

The background to the Oil Heating Association Clean Air Program at the Canadian Combustion Research Laboratory has been described in Mines Branch Investigation Report IR 73-32[1] entitled "Phase I: Facilities, Techniques and Procedures. The second and third phases of the program reported in IR 73-33[2] and IR 73-70[3] were concerned with the performance of six test burners in two types of warm-air furnaces equipped respectively with a stainless steel and a refractory combustion chamber.

This phase of the project is devoted to the performance characteristics of the same six test burners in a hot-water boiler and preliminary comparisons of this data with that obtained in the warm-air furnaces.

THE HOT WATER BOILER

The hot water boiler used in these tests was an American Standard Model 1340 equipped with a refractory combustion chamber. The manufacturers nameplate data is listed below:

TABLE 1

American Standard Boiler Model 1340

Manufacturers Nameplate Data

Input (max)	230,000 Btu/hr
Output (max)	169,000 Btu/hr
Firing Rate (max)	1.5 US gph
Nozzle Specification	70° Hollow or 70° Special Solid
Recommended Burner	American Standard Model DH 1300 Series

The boiler was incorporated into the closed loop circulation system illustrated in Figure 1. The system used a high capacity fan-assisted heat exchanger to simulate the heat outlet terminals that would normally be used in a domestic application. Adjustment of the heat exchanger fan permitted control of the return water temperature below 140°F throughout a test series.

The hot water circulating pump was disconnected from the automatic control unit and manually controlled to guarantee continuous circulation of water during all tests at all firing rates. The high temperature limit control was set at 180°F.

Each test burner was installed in the unit and performance was optimised at the standard draft condition (collar draft - 0.02 in. WC) as described in IR 73-32[1]; the water circulation and heat exchanger area were adjusted to give the water flow rates and temperature differentials listed in Table 2.

TABLE 2

Hot Water Circulation

Firing Rate US gph	Water Circulation gpm	Temperature Rise °F
0.5	2 - 2.5	20°
0.75	3.5 - 4	25°
1.00	4 - 4.5	30°

Subsequent performance measurements made during steady-state and transient operation were carried out in accordance with the schedule presented in IR 73-32[1].

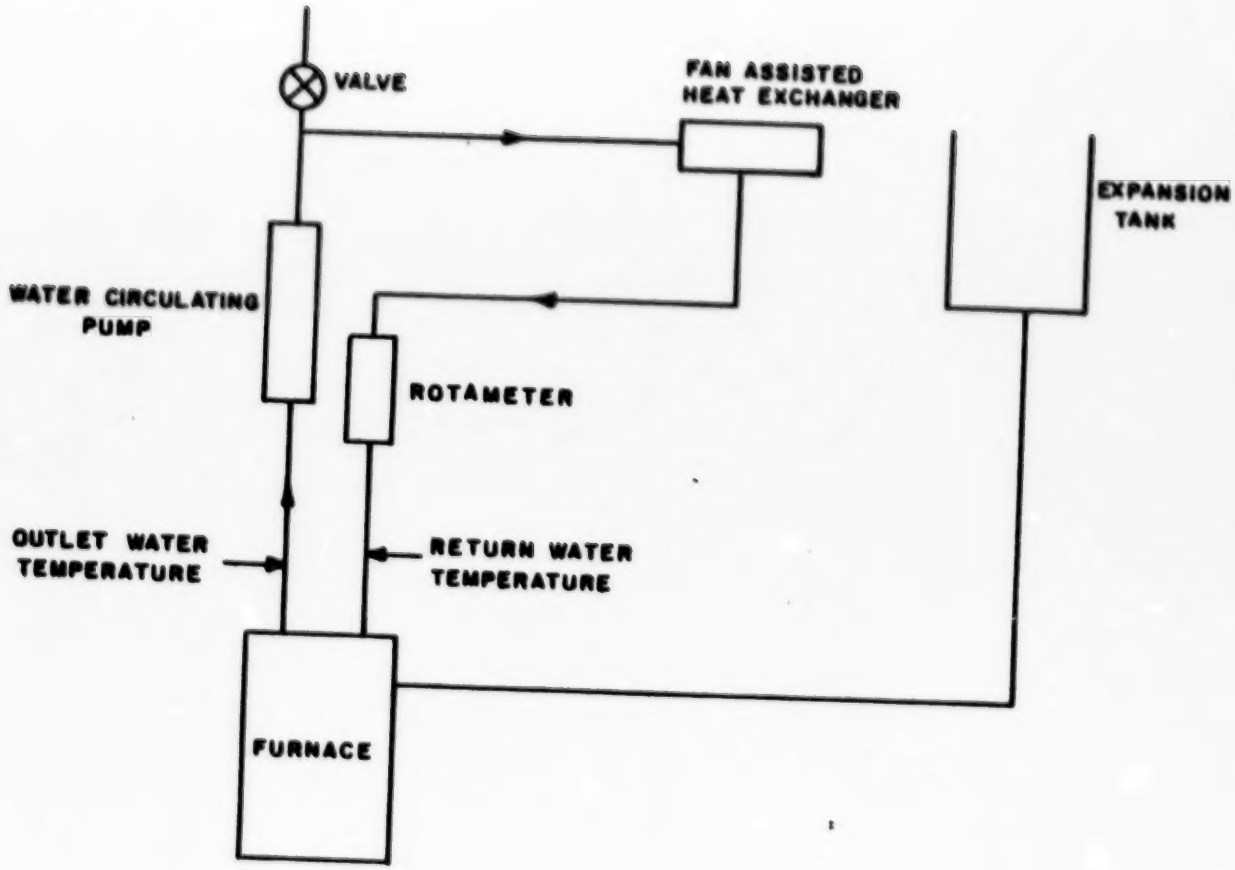

Figure 1. The hot water circulation system.

The discussion of the data is presented in the same order as the detailed test result tabulation in Appendix A.

STEADY RUNNING COMBUSTION PERFORMANCE

The test procedure required the burners to be adjusted to give a zero to one smoke number at a "standard" draft of -0.02 in. WC.

Combustion Performance at the Standard Draft Condition

The burner/firing rate combinations in which a smoke number below one could not be achieved at the standard draft are shown below:

TABLE 3

Burners not achieving Smoke Numbers Below 1

Burner	Firing Rate US gph	Minimum Smoke Number
Beckett S (1725 rpm)	0.5	2
Anthes (1725 rpm)	0.5	5
Terry (1725 rpm)	0.5	4
Terry (1725 rpm)	0.75	4

In addition to the unsatisfactory performance of the burners quoted in Table 3 several burners could only achieve a satisfactorily low smoke number at the expense of a high excess air level. The "unsatisfactory" excess air level was taken in previous investigations[3] to be 60 per cent. This is equivalent to a dry carbon monoxide content in the flue gas of less than 9 per cent.

TABLE 4

Burner/Firing Rate Combinations Leading a High Excess-Air Level

(CO_2 <9%)

Burner	Firing Rate US gph	CO_2 Level at Standard Draft %	Minimum Smoke Number
Aero 3450	0.5	8.8	0
Aero 3450	0.75	8.6	0
Beckett S (1725)	0.75	8.9	0
Beckett S (1725)	1.00	8.1	0
Anthes (1725)	0.75	8.6	<1
Aero (1725)	0.5	7.8	1

Combination of Tables 3 and 4 shows that ten out of the eighteen burner/firing rate combinations could not meet a combined standard of CO_2 > 9% and smoke number <1.

The poor performance offered by five of the six burners when fired at 0.5 US gph is in agreement with results from previous phases of the investigation when tests were carried out in warm air furnaces. No burner has given a satisfactory performance at this firing rate in any of the tests to date.

Combustion Performance Under Modified Draft Conditions

The modified draft conditions were obtained by altering the setting of the barometric damper without changing any of the burner controls. The results therefore reflect differences in performance that could be expected due to variations in external wind conditions.

The change to a higher draft level (-0.05 in. WC) led invariably to an increase in excess-air level which was never associated with a change in smoke number greater than unity.

The change to a reduced draft level (+0.05 in. WC) led invariably to a decrease in excess-air level and resulted in significant changes in the smoke number in some cases.

The changes in excess-air level due to the impressed changes in the chimney draft have been calculated as a percentage change in air flow through the burner per 0.01 inches WC change in chimney draft in Table A4.

When identical blast tube configurations were used with different speed motors (Aero 3450 and Aero 1725) the low speed motor was less susceptible to variations in chimney draft. Table A4 indicates that the burners equipped with low speed motors are less susceptible to changes in chimney draft; this conclusion must be considered with care since all the burners did not operate at the same mass flow rate under the standard condition. Consequently, changes in mass flow when expressed as a percentage of an already high mass flow rate may be unrealistically low. Table A5 lists the actual change in mass flow rate (per lb of fuel) and it can be seen that these changes became less significant as the firing rate increases.

The greatest susceptibility to draught change, as shown by the largest absolute changes in mass flow, occurred at the lowest firing rate when the relative change is at a maximum. This implies that the pressure drop across the blast tube is not adequate at the lower firing rate to guarantee good combustion and insensitivity to draught variations.

Smoke Production Under Modified Draft Conditions

The change to a reduced draft level led to significant smoke production in the several instances that are listed in Table 5.

TABLE 5

The Variation of Smoke Number With Draft Intensity

Burner	Firing Rate	Change in Smoke Number per 0.01 in.WC Change in Draft	
		Increased Draft	Reduced Draft
Beckett 3450	0.75		1.3
	1.00	All Burners	1.3
Aero 1725	0.5	<0.5	0.9
	0.75		1.1
Beckett 1725	0.5		0.9
Anthes 1725	0.5		0.5
	0.75		0.55
Terry 1725	0.75		0.6
	1.00		0.6

Carbon Monoxide Production Under Modified Draft Conditions

At the standard draft condition no burners produced more than 25 ppm CO; at the reduced draft condition (+0.05 inches WC) one burner at one firing rate (Beckett 3450 at 0.75 US gph) produced more than 25 ppm CO; at the increased draft condition (-0.05 inches WC) one burner (Anthes 1725 at 0.5 US gph) produced more than 25 ppm.

This result is similar to that obtained in the warm air furnace equipped with the refractory combustion chamber where three burner/firing rate combinations only were found to produce more than 25 ppm CO.

Nitric Oxide Emissions

A plot of the nitric oxide (NO) emissions at the standard draft condition is shown in Figure 2. The line shown is the "best fit" quadratic to the data points. A general increase in NO emission with firing rate can be seen despite the wide scatter in individual results. The emissions from burners when fired in this furnace were significantly (statistically) higher than those from the same burners when fired in the (stainless steel) Grimsby furnace and insignificantly (statistically) different from those measured when the same burners were fired in the (refractory) Anthes furnace.

The increase in NO emission observed when burners were fired in a furnace equipped with a refractory combustion chamber was most probably due to decreases in radiant and convective cooling of both the flame and the recirculated gases. Consequently, overall flame temperatures increased and accelerated those reactions producing NO.

Flue Gas Losses

The measured flue gas losses are shown in Table A8; also included in this table is a flue gas loss corrected to standard temperatures of 300°F and 400°F. It can be seen from the corrected flue gas losses that the highest loss (within the limits of accuracy of measurement) occurs with the lowest firing rate for all burners. This is a reflection of the poor combustion performance at this firing rate that has already been referred to.

The best performance at each firing rate was given by the following burners:

0.5 US gph	Beckett	(3450 rpm)
0.75 US gph	Beckett	(3450 rpm)
1.00 US gph	Aero	(1725 rpm)

The Aero 1725 rpm burner performed better than the Aero 3450 rpm at firing rates of 0.75 and 1.00 US gph.

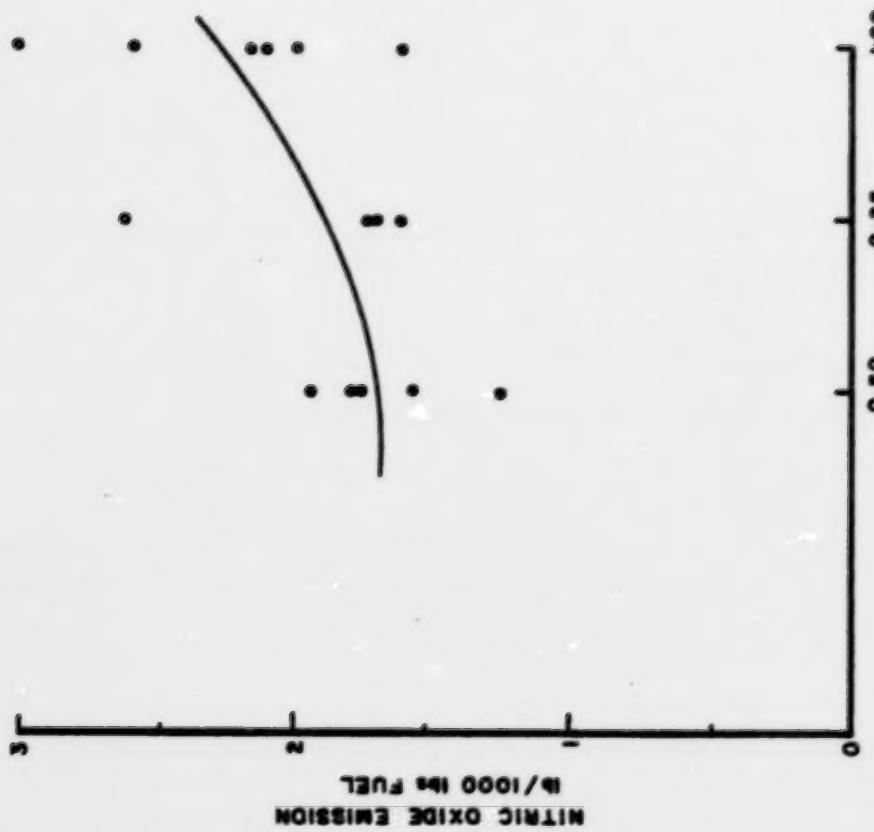

Figure 2. Nitric oxide emissions.

START-UP AND SHUT-DOWN COMBUSTION PERFORMANCE

Smoke Index on Start-Up and Shut-Down

It can be seen in Tables A9-A11 that:

In tests without a slip clutch the start-up gave a higher smoke index than the shut-down in 18 out of 54 tests.

In tests with a slip clutch the start-up gave a higher smoke index than the shut-down in 24 out of 53 tests.

The incorporation of a slip clutch reduced the smoke index in 39 out of 53 start-up tests and in 45 out of 53 shut-down tests.

Thus the incorporation of a slip clutch improved the shut-down performance relative to the start-up performance. It should be remembered that soot generated on shut-down comes from the flame alone whereas soot generated on start-up is a composite quantity of soot from the flame and soot detached (by the explosive ignition) from the heat transfer surfaces. Improvements in shut-down performance would therefore be expected to lead to improvements in start-up performance but not the reverse.

PEAK CARBON MONOXIDE CONCENTRATIONS ON START-UP AND SHUT-DOWN

The peak carbon monoxide levels on both start-up and shut-down were below 0.1%; except for the Terry burner when operated without a slip clutch.

Terry;	0.5 US gph;	-0.05 inches WC	Shut-Down	0.16% CO
Terry;	1.00 US gph;	+0.05 inches WC	Start-Up	0.21% CO
Terry;	1.00 US gph;	+0.05 inches WC	Shut-Down	0.25% CO

The incorporation of a slip-clutch led to the following changes in start-up and shut-down performance.

Better	start-up performance:	25 out of 54 tests
Worse	start-up performance:	9 out of 44 tests
	No change:	20 out of 54 tests
Better	shut-down performance:	22 out of 54 tests
Worse	shut-down performance:	10 out of 54 tests
	No change:	22 out of 54 tests

The degree of improvement or impairment was usually small; the three test conditions mentioned above where peak concentrations above 0.1% CO were recorded all showed a reduction in peak CO to below 0.1% after incorporation of the slip clutch.

THE PERFORMANCE OF THE TEST BURNERS IN DIFFERENT FURNACES

Steady Running Performance

Table 6 shows a comparison between burner performance in the three furnaces tested to date. It can be seen that no burner offers a satisfactory performance at all firing rates in all three furnaces.

At the highest firing rate the four retention head burners offer a satisfactory performance in all furnaces whereas the standard head burners do not; at the lowest firing rate no burner is consistently satisfactory; at the intermediate firing rate no consistent pattern is apparent.

The inability of the test burners to offer a satisfactory performance at the lowest firing rate appears to be unrelated to the head design (retention or standard). Retention head design for a firing rate of 1.00 US gph incorporates a central air orifice surrounding the oil nozzle and an annular air slot at approximately 1/2.R (R is the blast tube radius) This annular slot is not present on the heads used at the two lower rates

and it appears that at the lowest firing rate the mass flow through this single orifice does not produce a flow pattern within the flame that is adequate for a satisfactory level of combustion. As the firing rate is increased to the intermediate level (0.75 US gph) the higher mass flow generates a velocity field with steeper velocity gradients (and probably higher turbulence intensities) which improves the mixing between the conical fuel spray and the air supply. The general result is that for all burners performance improves with increased firing rate between 0.5 and 0.75 US gph.

If the performance of retention head burners is to be improved at the lowest firing rate it appears that a retention head must be designed specifically for these firing rates. The design will require a smaller central orifice than at present and an annular slot of small width situated at approximately the 1/2 R position.

TABLE 6

Burner Performance Levels in Different Furnaces

Burner		Firing Rate								
		0.5			0.75			1.00		
		G	A	AS	G	A	AS	G	A	AS
Beckett	3450	NS	NS	HS	HS	S	HS	HS	HS	HS
Aero	3450	NS	NS	NS	S	S	NS	HS	S	HS
Aero	1725	S	NS	NS	S	NS	S	HS	HS	HS
Anthes	1725	NS	NS	NS	NS	S	NS	HS	HS	HS
Terry	1725	NS	NS	NS	NS	S	NS	NS	S	S
Beckett	1725	NS	NS	NS	S	NS	S	NS	NS	NS

G: Grimsby Warm Air Furnace

A: Anthes Warm Air Furnace

AS: American Standard Hot Water Boiler

NS: Not Satisfactory: CO_2 <9%

S: Satisfactory: CO_2 9-10%

HS: Satisfactory: CO_2 10-11%

Nitric Oxide Emissions

The average emissions of nitric oxide (lbs/1000 lb fuel) for the three test furnaces are listed in Table 7. Although different burners show different characteristics with increased firing rate there is an overall trend towards increased nitric oxide emission with increased firing rate.

TABLE 7

Nitric Oxide Emissions at the Standard Draft Condition

Firing Rate US gph	Mean Nitric Oxide Emission lbs/1000 lbs Fuel		
	Grimsby Warm Air Furnace	Anthes Warm Air Furnace	American Standard Boiler
0.50	1.1	1.6	1.7
0.75	1.35	1.7	1.9
1.00	1.5	1.9	2.2

It appears that the lower wall temperature of the stainless steel combustion chamber consistently reduces the amount of NO produced by thermal fixation of atmospheric nitrogen.

Start-Up and Shut-Down Performance

A continuous recording smoke meter was not available during the first phase of the program when the burners equipped with high speed motors were undergoing evaluation in the warm air furnaces. Mean values of test data obtained in later evaluations are listed in Table 8.

It can be seen that the performance of the low-speed motor burners was significantly better in the refractory lined Anthes furnace both with and without the use of a slip clutch. This was initially ascribed to the high temperature of the refractory reducing soot accumulation during shut-down. By the same argument the burners should perform comparably in the American

standard boiler which also has a refractory lined combustion chamber. The performance in the American standard boiler although an improvement on that found in the stainless steel lined Grimsby furnace, did not achieve the same standard as that measured in the Anthes furnace. The reason for this is not apparent.

It is noticeable that the incorporation of a slip clutch (illustrated by the results in the American standard boiler, Table 8) is more effective on burners equipped with high speed motors than on burners equipped with low speed motors. Partial explanation of this is illustrated in Figure 3. Assuming that volume flow rate in proportional to motor speed a slip clutch with an engagement rpm 250 below the rated motor speed will engage at a volume flow rate closer to the control setting for high speed motors. The air deficiency at the time of initial fuel injection compared to the steady running condition is 7% for a high speed motor and 15% for a low speed motor. To realize the full benefit of delayed oil injection this air deficiency should be as small as possible.

TABLE 8

Mean Values of the Smoke Index for All Burners

Burner Type and Firing Rate (US gph)	Grimsby				Anthes				American Standard			
	A		B		A		B		A		B	
	Start	Stop	Start	Stop	Start	Stop	Start	Stop	Start	Stop	Start	Stop
High Speed Motors 0.5									3.5	8.4	.6	2
0.75									2.1	8.0	0	2.4
1.00									1.1	5.7	1.6	0.3
Low Speed Motors 0.5	5.9	6.0	7.3	3.1	2.3	3.4	1.1	0.3	6.1	4.6	4.2	3.8
0.75	3.9	5.0	6.6	3.0	2.0	3.2	1.1	1.0	3.8	6.2	3.1	4.3
1.00	5.9	5.2	5.0	1.5	1.5	2.8	1.1	2.3	3.1	5.8	4.1	5.3

A: Without Slip Clutch

B: With Slip Clutch

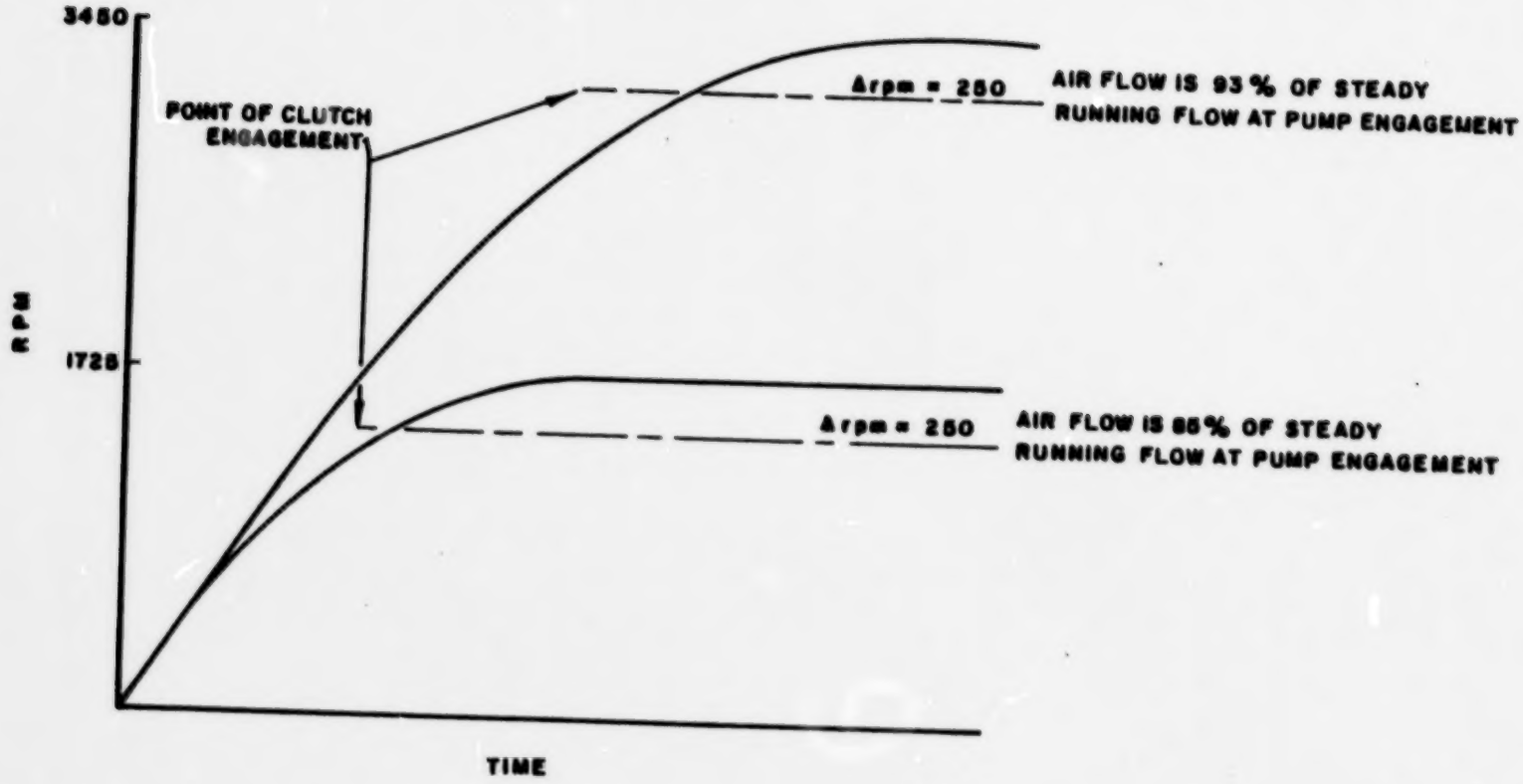
3450
1728
RPM
POINT OF CLUTCH ENGAGEMENT
Δrpm = 250
AIR FLOW IS 93% OF STEADY RUNNING FLOW AT PUMP ENGAGEMENT
Δrpm = 250
AIR FLOW IS 85% OF STEADY RUNNING FLOW AT PUMP ENGAGEMENT
TIME

Figure 3. Slip-clutch engagement.

CONCLUSIONS

Performance in the American Standard Boiler

Only one burner performed satisfactorily at all firing rates.

Ten out of eighteen burner/firing rate combinations could not meet a combined standard of CO_2 >9% and a smoke number less than one.

Increases in draft did not lead to changes in smoke number greater than one unit whereas decreases in draft led to greater increases in several instances.

The burners are least efficient and most susceptible to draft changes at the lowest firing rate.

The incorporation of a slip-clutch resulted in reduced smoke and carbon monoxide emissions on both start-up and shut-down in the majority of cases (79% and 82% respectively).

Performance in Different Furnaces

No individual burner offers a satisfactory performance at all firing rates in all furnaces tested to date.

All the burners show the worst performance at the lowest firing rate.

The nitric oxide emissions in all furnaces increase with firing rate; the emissions recorded from the Grimsby furnace were significantly lower than those from the other two.

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TABLE A1

STEADY-RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle US gph	Draft Inch WC	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Beckett 3450	0.5	+0.05	12.9	4.2	0	-	1
		-0.015	10.2	7.8	0	-	1
		-0.05					
Beckett 3450	0.75	+0.05	16.6	.01			9
		-0.02	11.25	5.5	0		0
		-0.05	11.7	6.3	0		0
Beckett 3450	1.00	+0.05	1.5	0	0		9
		-0.02	1.0	6.8	0		0
		-0.05	9.2	8.1	0		0
*Aero 3450	0.5	+0.04	11.4	6.8	0		0
		-0.02	8.8	9.3	0		0
		-0.045	7.3	10.7	trace		0
*Aero 3450	0.75	+0.055	10.0	6.9	0		0
		-0.02	8.6	8.8			
		-0.05	7.0	11.1	0		0
*Aero 3450	1.00	+0.05	13.2	.05	0		0
		-0.02	10.8	6	0		0
		-0.05	9.7	6.2	0		0

*Burner vents completely closed.

TABLE A2

STEADY RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle US gph	Draft Inch WC	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
*Aero	0.5	+0.05	11.6	4.3	0		6
		-0.02	7.8/8.6				1
		-0.75	8.2	9.2			2
*Aero	0.75	+0.05	14.4/13.8	0/1			9+
		-0.02	9.4	7.2			1
		-0.04	8.4	8.7			0
Aero	1.00	+0.05	14.4	0.15	.0015		
		-0.02	11.6	4.5			<1
		-0.55	9.4	7.2	0		0
Anthes	0.5	+0.06	8.4	8.5	20		9
		-0.02	6.5	11.6	10		5
		-0.07	5.4	13	35		5
Anthes	0.75	+0.07	11.2	5.1	0		6
		-0.02	8.6	8.8	0		<1
		-0.07	7.8	10.8	0		0
Anthes	1.00	+0.05	12.0	4	0		0
		-0.02	10.6	6	0		0
		-0.45	9.9	7.0	0		0

*Air band completely closed.

TABLE A3

STEADY RUNNING PERFORMANCE

Combustion Conditions

Burner	Nozzle	Draft Inch WC	CO_2 %	O_2 %	CO ppm	C_xH_y ppm	Smoke Number
Terry	0.5	+0.055	8.9	9.0	0		5
		-0.02	6.4	11.6			4
		-0.035	6	12			3
Terry	0.75	+0.06	9.9	6.2	0		9
		-0.02	7.7	9.4	0		4
		-0.05	7.8	10.8	0		3
Terry	1.00	+0.06	10.6	5.3	0		6
		-0.02	9	7.6	0		1
		-0.06	8.2	8.9	0		<1
Beckett S	0.5	+0.05	8.9	8.2	0		8
		-0.02	6	12.5	0		2
		-0.045	5.8	12.5	0		3
Beckett S	0.75	+0.065	11.2	6.0	0		1
		-0.02	9.0/8.8	8.1/8.4	0		0
		-0.05	7.9	9.7	0		0
Beckett S	1.00	+0.05	9.6	7.5	0		<1
		-0.02	8.1	8.85	T		0
		-0.055	7.6	10.3	0		0

TABLE A4

STEADY RUNNING PERFORMANCE

The Relative Effect of Furnace Collar Draft On Burner Mass Flow

Burner	Firing Rate US gph	Change in Air Flow: % per 0.01 Inch wc	
		Standard to -0.05 Inch WC	Standard to +0.05 Inch WC
Beckett 3450	0.5		3.45
	0.75	1.38	5.07
	1.00	2.96	5.23
Aero 3450	0.5	8.34	3.91
	0.75	4.63	1.91
	1.00	3.93	2.84
Aero 1725	0.5	3.3	4.83
	0.75	6.07	5.11
	1.00	6.98	3.17
Anthes 1725	0.5	0.63	4.12
	0.75	0.96	2.65
	1.00	2.93	1.77
Terry 1725	0.5	4.26	3.75
	0.75	0.43	2.82
	1.00	2.48	1.93
Beckett S 1725	0.5	1.17	6.88
	0.75	4.29	2.48
	1.00	1.89	2.27

TABLE A5

STEADY RUNNING PERFORMANCE

The Absolute Effect of Furnace Collar Draft On Burner Mass Flow

Burner	Firing Rate US gph	Change in Mass Flow: lbs per lb Fuel/0.01 Inch WC	
		Increased Draft	Reduced Draft
Beckett 3450	0.5		0.71
	0.75	.34	0.80
	1.00	.63	1.11
Aero 3450	0.5	2.00	0.93
	0.75	1.89	0.36
	1.00	0.76	0.55
Aero 1725	0.5	2.96	2.22
	0.75	1.36	1.14
	1.00	1.26	0.57
Anthes 1725	0.5	1.23	0.92
	0.75	0.96	0.65
	1.00	0.58	0.35
Terry 1725	0.5	1.41	1.24
	0.75	0.12	0.17
	1.00	0.58	0.45
Beckett S 1725	0.5	0.45	1.63
	0.75	1.01	0.59
	1.00	0.59	0.59

TABLE A6

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions

Burner	Firing Rate US gph	Nominal Draft Inch WC	Nitric Oxide Emissions	
			ppm	lb/1000 lb Fuel
Beckett 3450	0.5	-0.02	87	1.94
		-0.05	-	-
		+0.05	102	1.79
	0.75	-0.02	126	2.60
		-0.05	130	2.53
		+0.05	120	1.61
	1.00	-0.02	132	3.00
		-0.05	107	2.64
		+0.05	130	1.91
Aero	0.5	-0.02	69	1.78
		-0.05	62	1.92
		+0.05	80	1.59
	0.75	-0.02	-	-
		-0.05	72	2.32
		+0.05	93	2.19
	1.00	-0.02	121	2.57
		-0.05	102	2.40
		+0.05	178	3.05
Anthes	0.05	-0.02	52	1.8
		-0.05	46	1.91
		+0.05	52	2.21
	0.75	-0.02	61	1.61
		-0.05	53	1.67
		+0.05	96	1.95
	1.00	-0.02	93	2.00
		-0.05	79	1.82
		+0.05	122	2.31

TABLE A7

STEADY RUNNING PERFORMANCE

Nitric Oxide Emissions

Burner	Firing Rate US gph	Nominal Draft Inch WC	Nitric Oxide Emissions	
			ppm	lb/1000 lb Fuel
Terry	0.5	-0.02	45	1.58
		-0.05	38	1.42
		+0.05	64	1.63
	0.75	-0.02	59	1.78
		-0.05	55	1.59
		+0.05	67	1.54
	1.00	-0.02	84	2.12
		-0.05	70	1.94
		+0.05	88	1.91
Beckett S	0.5	-0.02	34	1.27
		-0.05	42	1.65
		+0.05	53	1.37
	0.75	-0.02	67	1.71
		-0.05	60	1.72
		+0.05	77	1.57
	1.00	-0.02	58	1.62
		-0.05	59	1.75
		+0.05	67	1.59
Aero	0.5	-0.02	58	1.86
		-0.05	68	1.89
		+0.05	89	1.75
	0.75	-0.02	67	1.62
		-0.05	70	1.89
		+0.05	110	1.74
	1.00	-0.02	107	2.11
		-0.05	86	2.09
		+0.05	121	1.87

TABLE A8

STEADY RUNNING PERFORMANCE

Flue Gas Losses at the Standard Draft Condition

Burner	Firing Rate US gph	CO_2 % Dry	Flue Gas Temperature °F	Flue Gas Loss, %		
				Measured	Corrected	
					300°F	400°F
Beckett 3450	0.5	10.2	215	10.0	12.42	15.3
	0.75	11.25	283	11.4	11.87	14.5
	1.00	10.0	245	10.9	12.53	18.4
Aero 3450	0.5	8.8	235	11.2	13.35	16.6
	0.75	8.6	300	13.5	13.5	16.8
	1.00	70.8	215	9.8	12.1	14.8
Aero 1725	0.5	7.8	213	11.0	14.2	17.9
	0.75	9.4	248	11.3	12.9	15.9
	1.00	11.6	310	12.0	11.7	14.2
Anthes 1725	0.5	6.5	230	12.7	15.8	20.1
	0.75	8.6	270	12.5	13.5	16.8
	1.00	10.6	318	12.7	12.2	14.9
Terry 1725	0.5	6.4	234	13.0	15.9	20.3
	0.75	7.7	268	13.1	14.3	18.0
	1.00	9.0	326	14.0	13.2	16.4
Beckett S 1725	0.5	7.4	250	12.7	14.6	18.5
	0.75	8.9	268	12.2	13.3	16.5
	1.00	8.1	328	14.9	13.9	17.6

TABLE A9

START-UP AND SHUT-DOWN PERFORMANCE

in the American Standard Boiler

Burner	Firing Rate US gph	Nominal Draft Inch WC	Smoke Index			
			Without Slip-Clutch		With Slip-Clutch	
			Start	Stop	Start	Stop
Beckett 3450 rpm	0.5	-0.02	3.2	4.3	1.2	2.6
		-0.05	6.4	4.1	0.7	2.1
		+0.05	2.8	8.8	2.6	5.8
	0.75	-0.02	1.5	3.8	0	1.9
		-0.05	5.3	1.7	3.8	2.4
		+0.05	6.5	5.9	1.9	4.1
	1.00	-0.02	0	0.3	1.7	0.5
		-0.05	1.1	0	1.5	0.5
		+0.05	1.6	1.5	0.8	1.0
Aero 3450 rpm	0.5	-0.02	3.7	12.4	0	1.4
		-0.05	3.4	11.4	0	0
		+0.05	4.6	8.9	0.6	0
	0.75	-0.02	2.6	12.1	0	2.8
		-0.05	5.1	9.3	0	0
		+0.05	3.6	14.7	0	0
	1.00	-0.02	2.2	11.1	1.4	0
		-0.05	2.9	6.5	0	0
		+0.05	7.5	14.4	1.0	0

TABLE A10

START-UP AND SHUT-DOWN PERFORMANCE

in the American Standard Boiler

Burner	Firing Rate US gph	Nominal Draft Inch WC	Smoke Index			
			Without Slip-Clutch		With Slip-Clutch	
			Start	Stop	Start	Stop
Aere 1725 rpm	0.5	-0.02	2.9	4.9	2.6	3.5
		-0.05	1.7	5.0	1.5	2.3
		+0.05	2.1	12.1	2.8	9.4
	0.75	-0.02	1.3	6.1	1.7	3.8
		-0.05	2.1	4.0	1.9	1.0
		+0.05	2.6	16.1	2.5	13.1
	1.00	-0.02	2.1	6.0	3.0	4.9
		-0.05	2.8	3.3	1.7	0.6
		+0.05	1.9	10.0		
Anthes 1725 rpm	0.5	-0.02	9.5	5.1	4.26	6.20
		-0.05	8.5	5.1	3.23	3.69
		+0.05	8.7	5.9	10.9	10.0
	0.75	-0.02	4.0	8.0	2.6	2.9
		-0.05	4.6	6.3	2.8	0
		+0.05	9.0	9.9	7.5	2.8
	1.00	-0.02	3.9	6.8	2.5	6.4
		-0.05	3.4	5.1	3.1	4.9
		+0.05	4.6	11.0	3.2	1.9

TABLE A 11

START-UP AND SHUT-DOWN PERFORMANCE

in the American Standard Boiler

Burner	Firing Rate US gph	Nominal Draft Inch WC	Smoke Index			
			Without Slip-Clutch		With Slip-Clutch	
			Start	Stop	Start	Stop
Terry		-0.02	5.8	4.0	3.7	3.2
1725 rpm	0.5	-0.05	5.2	2.3	3.7	1.8
		+0.05	9.2	8.8	5.4	6.7
		-0.02	7.7	7.4	5.6	3.4
	0.75	-0.05	3.2	5.1	1.9	2.3
		+0.05	9.7	8.9	11.2	8.4
		-0.02	2.8	6.0	8.0	8.4
	1.00	-0.05	2.5	2.3	4.2	4.9
		+0.05	2.1	12.9	9.4	10.5
Beckett S		-0.02	6.2	4.5	6.4	2.3
1725 rpm	0.5	-0.05	4.0	2.9	3.8	0.7
		+0.05	6.6	7.7	8.4	6.9
		-0.02	2.0	3.3	2.4	6.9
	0.75	-0.05	3.3	3.2	1.7	0
		+0.05	7.2	8.2	6.2	4.0
		-0.02	3.7	4.4	2.7	1.4
	1.00	-0.05	3.0	3.0	2.4	0
		+0.05	8.8	7.6	4.5	1.44

TABLE A12

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch WC	Peak Carbon Monoxide Concentration			
			Without Slip-Clutch		With Slip-Clutch	
			Start	Stop	Start	Stop
Beckett 3450 rpm	0.5	-0.02	.007	.007	.007	.007
		-0.05	0	0	0	0
		+0.05	.01	.01	0	0
	0.75	-0.02	.007	.007	.02	0
		-0.05	0	0	0	0
		+0.05	.05	0	.03	0
	1.00	-0.02	0	0	0	0
		-0.05	0	0	0	0
		+0.05	.03	0.01	.01	0
Aero 3450 rpm	0.05	-0.02	0	0	0	0
		-0.05	0.01	0.01	0.01	0.01
		+0.05	0	0	0	0
	0.75	-0.02	0.01	0.02	0	0
		-0.05	0	0	0	T
		+0.05	0.01	0.01	0	0
	1.00	-0.02	0.035	0.06	0	0
		-0.05	0.007	0.01	0	0
		+0.05	0.05	0.04	0	0

TABLE A13

START-UP AND SHUT-DOWN PERFORMANCE

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch WC	Peak Carbon Monoxide Concentration			
			Without Slip Clutch		With Slip Clutch	
			Start	Stop	Start	Stop
Aero	0.5	-0.02	0	0	0	0
		-0.05	0	0	0	0
		+0.05	0	0	0	0
	0.75	-0.02	0.01	0	0	0
		-0.05	0.007	0.01	0	0
		+0.05	0.06	0.02	0	0
	1.00	-0.02	.02	.01	0	0
		-0.05	0	0	0	0
		+0.05	0	0	0.04	0.02
Anthes	0.5	-0.02	0	0	.06	0
		-0.05	0	0	.04	.06
		+0.05	0	0	.02	.03
	0.75	-0.02	0	0	0	0
		-0.05	0.007	0.007	0	0
		+0.05	0.015	0.01	0	0
	1.00	-0.02	0.007	0.007	0	0
		-0.05	0	0	0	0
		+0.05	0.06	0.08	0	0

TABLE A14

START-UP AND SHUT-DOWN CONCENTRATIONS

Peak Carbon Monoxide Concentrations

Burner	Firing Rate US gph	Nominal Draft Inch WC	Peak Carbon Monoxide Concentration			
			Without Slip Clutch		With Slip Clutch	
			Start	Stop	Start	Stop
Terry	0.5	-0.02	.05	.03	.02	0
		-0.05	0.04	0.16	.007	0
		+0.05	0	0	.04	.03
	0.75	-0.02	0	0	.007	.007
		-0.05	0	0	.007	.007
		+0.05	0	0	.007	.007
	1.00	-0.02	0	0	0	0
		-0.05	0	0	0	0
		+0.05	.21	.25	.01	.007
Beckett S	0.5	-0.02	0.02	0	0.025	0
		-0.05	0.03	0.07	0.02	0.02
		+0.05	0	0	0	0
	0.75	-0.02	0.007	0.007	0	0
		-0.05	0.007	0.007	0	0
		+0.05	0.015	0.007	0	0
	1.00	-0.02	0.015	0	0.005	0
		-0.05	0	0	0	0
		+0.05	0.007	0.007	0	0